

# EARTH OBSERVATIONS FROM SPACE

## HISTORY, PROMISE, AND REALITY

### EXECUTIVE SUMMARY



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Space Studies Board  
National Research Council



# EARTH OBSERVATIONS FROM SPACE

## History, Promise, and Reality

Executive Summary

Committee on Earth Studies  
Space Studies Board  
Commission on Physical Sciences, Mathematics, and Applications  
National Research Council

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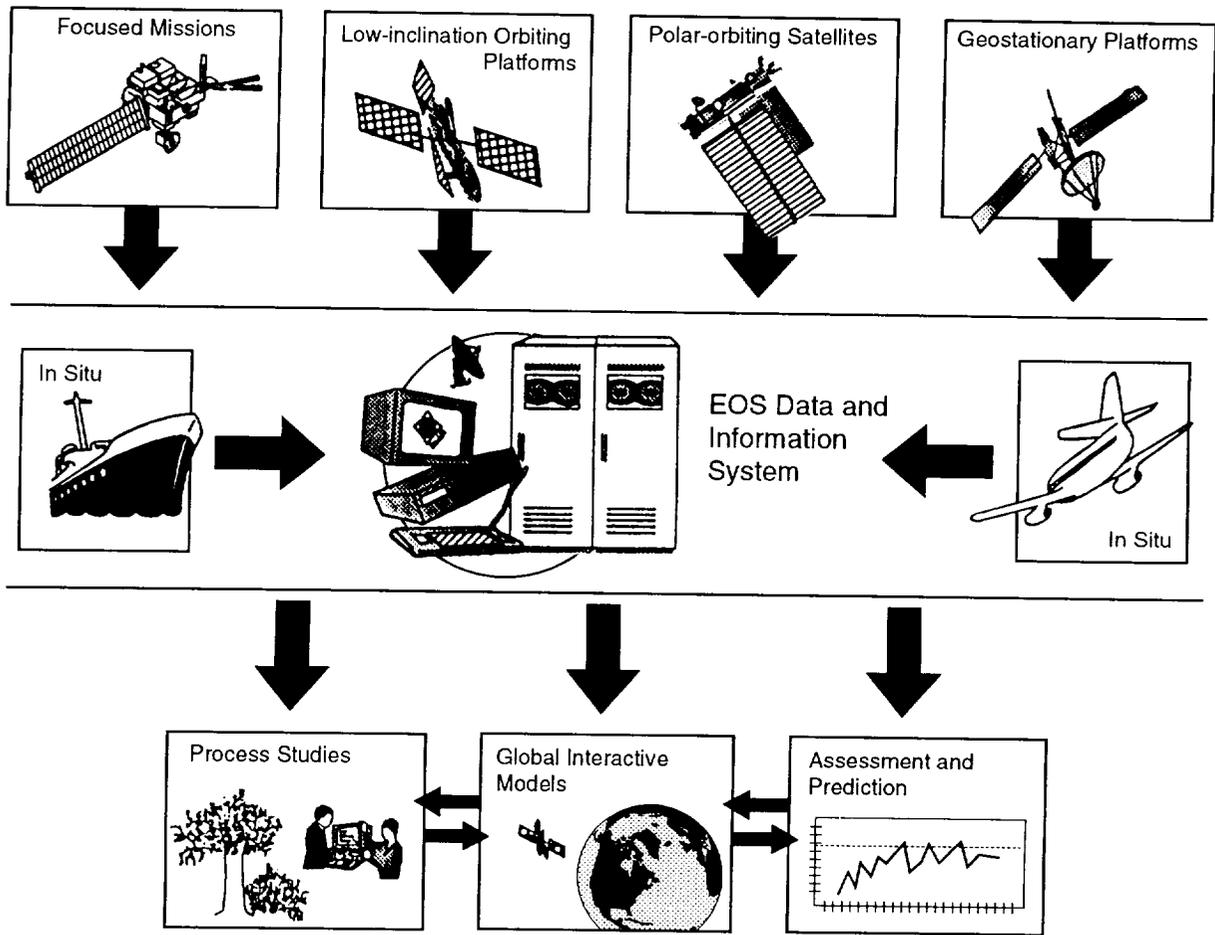
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The Elements of Mission to Planet Earth



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Every year if not every day  
we wager our salvation  
upon some prophecy  
based upon imperfect knowledge.

—Oliver Wendell Holmes  
1809-1894

# Preface

The Space Studies Board (SSB) and its committees conduct periodic reviews of the status of space science and applications. The most recent SSB reports on earth observations include *Space Science in the Twenty-First Century, Imperatives for the Decades 1995 to 2015—Mission to Planet Earth* (Task Group on Earth Sciences, National Academy Press, Washington, D.C., 1988), *Strategy for Earth Explorers in Global Earth Sciences* (Committee on Earth Sciences, National Academy Press, 1989), and *Assessment of Satellite Earth Observation Programs—1991* (Committee on Earth Studies, National Academy Press, 1991). This current report was written by the SSB's standing Committee on Earth Studies (CES). Since the most recent reports on earth observations, major changes have occurred in (1) the breadth of the SSB/CES charter, (2) the policy and budget environment in which the national civil earth observations programs are being conducted, and (3) the content of the earth observations programs themselves. The committee comments on the first of these matters below and expands on the others in Chapter 1.

An important objective of the CES has been to assemble a coherent history of the Mission to Planet Earth (MTPE) program. The committee members (see Appendix B) found this to be a challenging task but believed that it was important to undertake it while it remained feasible. To achieve this objective, the CES considered it essential to collect in a single document the numerous threads that have been intertwined to create the earth observations programs that exist today, and to do so in a manner that would not require readers to have access to limited-distribution documents. For all practical purposes, many of the key documents are already nearly unavailable. Some readers may be disconcerted by the lengthy extracts included in this report, but the committee found their inclusion to be the best way to capture the origins, rationale, and critiques of the MPTE program. To give some measure of the background materials, the committee notes that its library of relevant documents occupies some 40 feet of bookshelves.

Although this report originated within the SSB, the CES also refers to the numerous reports and recommendations from other boards and committees of the National Research Council (NRC) that address earth observations, as well as to the critiques and recommendations of other advisory bodies since the publication in 1982 of *Global Change: Impacts on Habitability*, a NASA study chaired by Richard Goody. In the aggregate, literally hundreds of recommendations have been made regarding the conduct of earth observations.

Figure P.1 illustrates some of the complexities that arise in reviewing earth observations programs. The first problem is that space-based observations are a measurement *means* rather than an *end* in themselves. They serve earth science and applications needs that also rely on terrestrial in situ measurements and analytical studies and that employ integrated data sets (both current and historical) and mathematical models of physical-chemical-biological processes. Therefore, although the principal focus of this report is space-based observing systems, the broader perspective cannot and must not be ignored. As shown in Figure P.1, space-based observations consist of NASA's MTPE, which is the umbrella program encompassing the Earth Observing System (EOS), Earth Probes, and

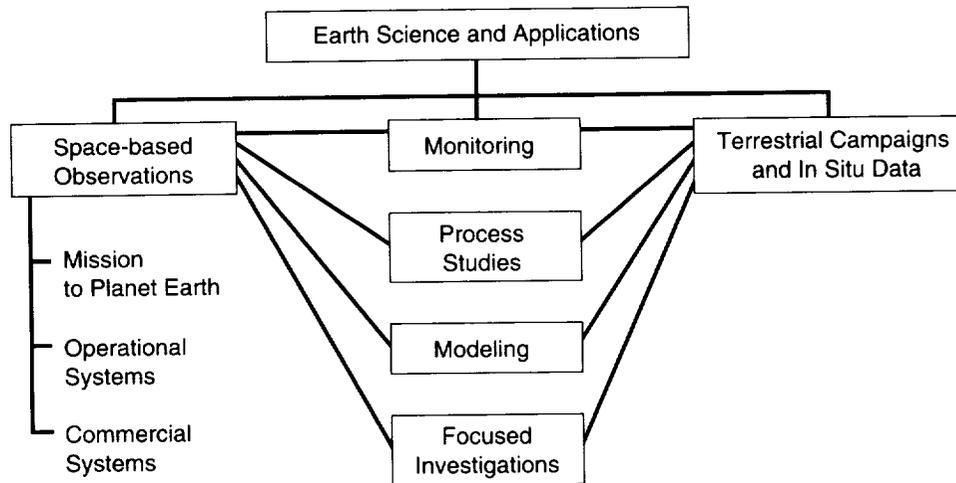


FIGURE P.1 Interrelationships among earth observations programs.

Landsat-7; the operational systems of NOAA and the Air Force's Defense Meteorological Satellite Program (DMSP); and commercial systems whose data may be integrated into the overall activity as well.

Both space-based and terrestrial systems support monitoring, process studies, modeling, and focused investigations of specific phenomena. Monitoring serves operational forecasting requirements, produces long-term records of earth system trends, and may capture episodic events that would otherwise be missed. Process studies clarify the interactions of physical-chemical-biological parameters. Monitoring and process studies jointly provide boundary conditions and mathematical descriptions of the mechanisms required in predictive models of the earth system. Targeted investigations are used to address focused scientific questions.

Insofar as NASA is concerned, the charter of the CES is unchanged since the SSB's 1991 *Assessment of Satellite Earth Observation Programs*, in which it was stated (emphasis added),

The Committee on Earth Studies (CES—called the Committee on Earth Sciences prior to 1989) provides continuing guidance to the Space Studies Board (SSB) in the areas of earth sciences and related remote sensing applications. *The scope of its scientific advice incorporates all earth science disciplines that can be addressed from space, including studies of the atmosphere, ocean, geology and geophysics, global biology and ecology, and their interactions.* The committee also identifies policy issues and provides advice concerning priorities in civil and unclassified remote sensing of the Earth, with special attention given to institutional roles and relationships among the various academic, government, and private sector entities involved. As a standing committee of the SSB, the CES assists in carrying out studies, monitoring the implementation of strategies, and providing recommendations to the National Aeronautics and Space Administration (NASA) and other government agencies.

The above charter could be interpreted to include NOAA's satellites from the perspective of their interface with the NASA program. However, the charter was broadened by a specific request from NOAA in 1991 to review its planning for future operational observation systems. NOAA asked that the CES examine NOAA's

- operational polar-orbiting satellites,
- geostationary satellites,
- extensive international partnerships, on which NOAA relies in both space and terrestrial activities,
- ties to the Air Force's DMSP, and
- future plans.

Even in advance of the Administration's recent decision to merge the NOAA and Air Force systems, the NOAA request also led to a more detailed examination of the DMSP than might have been inferred from the original CES charter. The DMSP and NOAA's Polar-Orbiting Environmental Satellite (POES) spacecraft have from the outset provided mutual backup and complementary data, and have consequently been operationally intercoupled for

a considerable period. The DMSP has also provided unique data important to the civil research and applications communities (notably from its Special Sensor Microwave Imager, or SSM/I).

The writing of this report has been a difficult and laborious task. The range of science, engineering, policy, and programmatic topics is very large and taxed the committee's abilities to their limits. If the CES has succeeded in its task, the report that follows will serve as a comprehensive foundation for the future reviews of the U.S. civil earth observations program.

John H. McElroy, *Chair*  
Committee on Earth Studies



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from which this Executive Summary is extracted,  
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It is our duty to proceed from what is near to what is distant, from what is known to that which is less known, to gather the traditions from those who have reported them, to correct them as much as possible and to leave the rest as it is . . . .

—Abu'l-Rayhan Muhamad al-Biruni  
973-1050



# Executive Summary

The ability to make earth observations from space is one of the great successes of the space age. For both scientists and operational users of the data, however, this success has been tempered with disappointment. The promise of the technology has not yet been realized, nor is it evident that current activities are leading toward a timely realization of that promise. The civil earth observations programs of the National Aeronautics and Space Administration (NASA) have been in a state of annual redesign for more than 5 years. The early momentum that led to the laudable concept of NASA's Mission to Planet Earth (MTPE) is being dissipated.

In this report the Committee on Earth Studies (CES), a standing committee of the Space Studies Board (SSB) within the National Research Council (NRC), reviews the recent history (nominally from 1981 to 1995) of the U.S. earth observations programs that serve civilian needs. The principal observations programs examined are those of NASA and the National Oceanic and Atmospheric Administration (NOAA). The Air Force's Defense Meteorological Satellite Program (DMSP) is discussed, but only from the perspective of its relationship to civil needs and the planned merger with the NOAA polar-orbiting system.

The report also reviews the interfaces between the earth observations satellite programs and the major national and international environmental monitoring and research programs. The monitoring and research programs discussed are the U.S. Global Change Research Program (USGCRP), the International Geosphere-Biosphere Program (IGBP), the World Climate Research Program (WCRP), related international scientific campaigns, and operational programs for the sharing and application of environmental data.

It is not the intent of the CES to make detailed reviews of every aspect of this broad scope of activities, nor is it the intent to provide detailed findings and recommendations for action by responsible agencies. Instead, the purpose of this report is to provide a broad historical review and commentary based on the views of the CES members, with particular emphasis on tracing the lengthy record of advisory committee recommendations. Any individual topic could be the subject of an extended report in its own right. Indeed, extensive further reviews are already under way to that end. If the CES has succeeded in the task it has undertaken, this report will serve as a useful starting point for any such more intensive study.

The report is divided into eight chapters: (1) an introduction, (2) the evolution of the MTPE, (3) its relationship to the USGCRP, (4) applications of earth observations data, (5) the role that smaller satellites can play in research and operational remote sensing, (6) earth system modeling and information systems, (7) a number of associated activities that contribute to the MTPE and the USGCRP, and (8) organizational issues in the conduct of civil earth observations programs. Following the body of the report is a series of appendixes: after a list of acronyms and abbreviations and collected short biographies of CES members, six brief tutorials discuss several scientific topics important to the science and applications of earth observations. Highlights from the eight chapters follow.

## EARTH SCIENCE FROM SPACE AND THE EVOLUTION OF THE MISSION TO PLANET EARTH

The NASA effort in earth observations is called the Mission to Planet Earth. It includes (1) a number of intermediate-size satellites that are collectively called the Earth Observing System (EOS); (2) a series of smaller satellites called Earth Probes; (3) a major information system named the EOS Data and Information System (EOSDIS); (4) associated research, data analysis, and mission operations activities; and (5) the Landsat-7 satellite, which will be the joint responsibility of NASA and NOAA. In addition, the MTPE relies on the availability of data from NOAA's operational satellites, the DMSP satellites (up to the point of their merger with the NOAA polar-orbiting satellites), and numerous foreign satellites—some wholly foreign owned, others carrying NOAA or NASA instruments in cooperative ventures.

The Mission to Planet Earth began as a scientific initiative called Global Habitability, which had its origins in the research and operational earth observations missions of the 1960s and 1970s. The Global Habitability effort culminated in the report of a NASA workshop chaired by Richard Goody entitled *Global Change: Impacts on Habitability* (JPL, 1982). The next step in the advancement of the idea came in the report of an NRC workshop chaired by Herbert Friedman entitled *Toward an International Geosphere-Biosphere Program* (NRC, 1983). The concept continued to evolve and took much of its present form from the seminal work of the Earth System Science Committee (ESSC), which was chaired by Francis Bretherton (NASA, 1986, 1988). These three pivotal efforts became known colloquially as the Goody, Friedman, and Bretherton reports.

The MTPE was allied early with the Space Station program. As a result of that tie, the program took the initial form of a satellite design using very large, highly complex, astronaut-tended, polar platforms that would be serviced from the Space Shuttle, which was required to fly in a polar orbit for this purpose. After planning for launches of the Space Shuttle into polar orbit and astronaut servicing of platforms there was eliminated, the separation of the MTPE from the Space Station program soon followed. A continuous series of reviews, redesigns, budget reductions, and changes in scope has led to the current configuration that employs intermediate and smaller satellites. Reviews are ongoing in 1995, with Congress calling for a reexamination of the program by NASA, the General Accounting Office (GAO), the Marshall Institute, and the NRC.

The continuing redesign has led to (1) large amounts of discarded work, (2) a reduction in the scientific and technical scope of the effort, (3) a retreating series of dates for the achievement of the originally stated scientific and technical goals, and (4) a continuous distraction for the scientists and administrators attempting to carry out the program. It is the CES's perception that a substantial fraction of the overall effort conducted over a period of 5 years, particularly that by people within NASA, has been devoted to responding to calls for changes to the program from the Administration, the agency, and Congress.

Approximately 6 years prior to the present report, a blue-ribbon panel was formed to examine the future of the U.S. civil space program; it was chaired by one of the nation's most prominent industrial leaders. The panel's report noted (Augustine, 1990),

"Management turbulence" [is] defined as continual changes in cost, schedule, goals, etc. . . . Each change induced has a way of cascading through the entire project execution system, producing havoc at every step along the way. . . . At each step, contracts must be renegotiated, people reassigned, designs changed and schedules revised. Soon a disproportionate amount of time is spent in the pursuit of these change practices instead of producing the end product itself.

The report also noted,

The impact of excessive revisions in research contracts conducted by universities has much the same effect. In this case, substantial effort is devoted by academic researchers to the preparation of proposals for research support. When the presumed funds to support the work are subsequently diverted to other objectives, the productive talents of some of the nation's most able people are largely wasted.

The CES finds the Augustine panel's language to be an accurate and troubling description of what has overtaken the MTPE.

## MISSION TO PLANET EARTH AND THE U.S. GLOBAL CHANGE RESEARCH PROGRAM

The U.S. Global Change Research Program (USGCRP) was created in response to public concerns regarding environmental change and stemmed from earlier national and international programs (e.g., the WCRP, United Nations Environmental Program (UNEP), IGBP, and NASA's work leading up to the MTPE). An early characteristic of the USGCRP was the tendency to include under its umbrella nearly all preexisting environmental programs within federal agencies, whether or not they were part of an organized, coherent program of research on global change.

In the context of this report, *climate change* refers to changes on time scales from a few years to a few centuries in the climate. Following Lorenz (1975) and Peixoto and Oort (1992), *climate* is defined as "the mean physical state of the climate system . . . , consisting of the atmosphere, oceans, and cryosphere. The 'mean physical state' is defined as a set of averaged quantities complete with higher moment statistics . . . that characterize the structure and behavior of the atmosphere, hydrosphere, and cryosphere." Peixoto and Oort make an important distinction between *climate* and *weather*: "The climate . . . can be considered as 'average weather,' complete with some measures of the variability of its elements and with information on extreme events." Some variables that are relevant in weather and in other branches of meteorology are also important in the characterization of climate.

In spite of its title, agency budget pressures and prioritization decisions have greatly reduced the scope of the USGCRP from *global change* to the narrower *global climate change*. Some areas of scientific research and remote sensing that have near-term scientific importance or serve practical applications have been reduced in scope or eliminated (e.g., land surface and vegetation research employing high-spatial-, high-spectral-resolution electrooptic sensors and microwave and laser sensing of oceans and ice).

When the current program was formulated, it was assumed that Landsat-like data would continue to be available. Now, however, it is the view of the CES that the combination of the loss of Landsat-6 and the cancellation of other advanced electrooptical sensors leaves a substantial gap in medium- to high-spectral-resolution and high-spatial-resolution measurements needed to meet the USGCRP objectives. Global surveys of vegetation class, land use, and surface minerals, as well as contributions to cartography, are not included in current plans. As structured, the USGCRP will also not generate some other data of substantial value to the earth applications community, such as systematic regional and global topography, digital elevation maps, and magnetic and gravitational fields.

The active microwave oceanographic and cryospheric measurements for the USGCRP (altimetry, scatterometry, and synthetic aperture radar, or SAR) are not integrated into a coherent plan either for their eventual transfer to long-term research or operational status on future NOAA satellites or for securing the timely availability of these data from foreign and/or internationally cooperative systems.

Alterations in vegetation class and extent are obviously changes in surface properties of great human interest; they are also changes that can be monitored from space. Such changes may develop because of climate change. The reduction in scope of the USGCRP to focus more narrowly on global climate change reduces the capability to make these measurements. At the same time that reductions in scope have been directed, policymakers are asking for nearer-term answers upon which to base decisions—in effect, re-expanding the scope of the effort.

The previously mentioned reductions now make the United States increasingly reliant on other nations for spacecraft, sensor systems, and data in some areas in which the United States was preeminent, notably high-spectral- and high-spatial-resolution electrooptical and microwave measurements. The CES enthusiastically endorses the concept of sharing the burden for the conduct of earth observations among as many nations as possible. However, the diminution of the ability of the United States to obtain required data from its own systems places a greater importance on the reliability of international agreements than in the past. In the past, these agreements have been difficult to reach and have not always resulted in ready data availability. This difficulty has been present in even such commonplace data as coarse-spatial-resolution meteorological measurements.

The USGCRP includes efforts of NASA, NOAA, the Department of Interior (DOI), Department of Agriculture (USDA), Department of Energy (DOE), Environmental Protection Agency (EPA), National Science Foundation (NSF), and others. As a result, responsibility for the USGCRP involves more than a dozen agencies, their respective budget examiners, and several dozen congressional committees, making efficient management improbable, or at least quite difficult.

USGCRP oversight is carried out by an interagency committee, which has provided useful coordination, but which also has little authority, offers inadequate means to review progress against milestones, and must rely on its powers of persuasion to conduct normal program management functions. For example, reallocation or redirection of program elements in an efficient manner (in response to changing needs or new discoveries) is hampered by the number of agencies and budget processes involved.

## APPLICATIONS PROGRAMS

Advancing the operational utility of civil earth observations has not been given national priority in the current efforts. In the environmental satellite programs of NOAA, no systematic program has been formed to replace the NASA Operational Satellite Improvement Program (OSIP), which was abruptly terminated early in the 1980s and upon which NOAA had relied. In its stead, the U.S. operational weather satellite program has only a limited internal research and development arm addressing needed improvements in the current generation of sensor systems and requirements for the next generation of sensors. New sensors are being pursued under the EOS program, but—despite some NOAA participation—with relatively little consideration for their affordability or practicality for transfer to operational use.

Under current NOAA planning, only small or incremental improvement of operational capabilities will take place over the next decade or even longer, even though the nations of the world plan to launch some 50 new observation satellites in that period (BNSC, 1992). Indeed, the polar-orbiting satellites of NOAA are little changed since the launch of the Advanced Tiros-N (ATN) in 1978. Thus, a period of some 27 years has elapsed between generations during a time of great technological advancement.

Of particular significance, no plans yet exist for the incorporation in the operational U.S. weather satellite fleet of advanced microwave instrumentation for altimetry, measurement of sea surface winds and waves, and imaging of polar ice fields—or, if not carried on U.S. satellites, for ensuring the routine availability of these data to operational users from foreign satellite systems. The CES questions the absence of an organized, advanced R&D program for the systematic introduction of these appropriate new technologies.

Landsat-like data are a necessary element in global change research and in operational applications. In spite of that, the future availability of these data is not ensured as of early 1995. The current U.S. role in this area rests solely with the aging Landsats-4 and -5. The future availability of these data to U.S. users rests on a Landsat-7 satellite planned to be launched in 1998 and on the commercial and data exchange practices of foreign countries. Similarly, as noted in the preceding section on the USGCRP with regard to research, no plans exist for the exploitation of space-based imagery in the preparation of topographic maps, digital elevation models, global vegetation inventories, mineral and soil surveys, or updated standard maps. Such products are among the greatest benefits to be derived from the nation's investment in its space program.

The problems associated with space applications in general, and with earth observations in particular, are of long standing. Ten years ago, the NRC's Space Applications Board (SAB) wrote (SAB, 1985),

The civil space program of the United States is a study in contrasts. The shuttle program is now operational; funding for the space station has been included in the President's FY 1986 budget. In the field of science, the NASA program in physics and astronomy (for example) is strong and has received increases in funding. Several NASA research programs involving earth observations, the Upper Atmosphere Research Satellite (UARS), the Earth Radiation Budget Experiment (ERBE), and the development of an instrument to measure wind speed at the ocean surface are moving ahead vigorously.

There is, however, one major sector of the space program that is in disarray: the operational remote sensing of the earth. The successful weather satellite system in NOAA has been severely affected by programmatic reductions, by stretch-outs in satellite procurement, and by reduced cooperation between NOAA and NASA. The land remote sensing effort is endangered as the attempt to turn the program over to the private sector threatens to flounder because of limitations placed on federal support. No civil operational program in ocean remote sensing is in place or planned, although the Navy (with the cooperation of NASA and to a lesser degree NOAA) plans to mount a significant effort, the Navy Remote Ocean Sensing Satellite (NROSS).

Information from operational earth remote sensing systems is needed for a host of practical purposes, such as weather forecasting, ocean transportation and utilization, land management, and mineral exploration. This information is also required to improve understanding of various earth sciences—meteorology, oceanography, geology, and geophysics. Not only practical applications of substantial economic importance but also the advance of earth-oriented science are inhibited by the inadequacies of this sector of the space program.

Why should such a practical program be floundering? Why is it that earth-oriented activities are being outdistanced by other, less applicable sectors of the space program? It is true that the surge into space is largely an investment in the future, but one might assume that we as a nation would make every effort to reap the benefits of our investment as soon as it became possible to do so. This is not being done. Indeed, the situation is even less logical than has already been stated: In at least one critical area of earth remote sensing, the United States is marking time as other countries move toward world leadership and prepare to reap the benefits of our investment—using technology developed in this country.

... We do not condone or accept as appropriate the disarray in operational earth remote sensing.

These observations remain valid a decade later.

### **SMALLER SATELLITES AND EARTH PROBES**

The CES believes that it is desirable for the nation's civil earth observations program to include both long-term elements and other elements that permit quick-response, rapid-turnaround measurements. Satellites of all sizes are likely to be required, with each filling a particular niche.

Smaller satellites can play a scientifically important role in the MTPE and can also play important operational roles. The CES and other bodies within the NRC have long endorsed the use of smaller missions (see, e.g., SSB, 1988a,b, 1991; ASEB, 1994). The CES notes, however, that the choice of satellite size should be made by applying well-understood systems engineering procedures to the task to be accomplished. The very large polar platforms proposed for the MTPE in the early 1980s were a mistake. In retreating from that mistake, however, the pendulum must not be allowed to swing so far in the opposite direction that we lose sight of the function the satellite is intended to serve. The program should not be detrimentally driven by the pursuit of still another technological objective.

Furthermore, the CES sees no pressing need within the domain of civil earth observations to fly satellites as a management demonstration simply to prove that small, modestly capable satellites can be launched quickly. Well-crafted experimental technology satellites, however, can serve as engineering testbeds to qualify new subsystems for later use in research and operational observation systems; but such testbeds are quite likely to be of a different character than satellites intended to observe long-term changes in climate variables. NASA's Advanced Communications Technology Satellite (ACTS) is illustrative of the difference: it demonstrates new technologies for later adoption, but is not itself in a form that would permit its use or replication as an operational commercial communications satellite. CES concerns arise only when mission objectives are mixed and demonstrations of new technology are appended as a requirement for the conduct of a mission in such a manner as to thwart scientific objectives or add unwarranted costs and delays. Astronaut-serviceable platforms should not be mandated as a requirement, and the use of microsattellites should not be mandated either.

It is important to recognize that technology changes and that the boundary between what measurement requires a larger satellite and what can be accomplished with a smaller satellite is not static. Some technological areas will be advanced with ease, making the boundary quite dynamic, while other areas will prove more resistant to advances—or will encounter basic limits likely to be of long standing. Sound and objective engineering judgment must be applied to determine the location of the boundary in individual cases.

### **EARTH SYSTEM MODELING AND INFORMATION SYSTEMS**

Large information systems and accurate earth system models are easier to imagine than they are to build. Constructing earth system models possessing predictive skill of a useful degree is among the most challenging research tasks humans have undertaken. As with information systems, the state of earth system modeling is rudimentary, and the production of models must proceed incrementally, allowing for frequent adjustments in approach. The mathematical methods, algorithms, visualization approaches, software design, and other aspects of earth system modeling all have major embedded research tasks. Furthermore, present and probable future modeling capabilities should be factored into the design of observational systems. Both models and observational systems should be designed such that—as far as is reasonably possible—continuity, sampling frequency, and accuracies are commensurate with the needs for understanding and simulating the behaviors of the components of the earth system.

The subject of earth system modeling has received considerable attention by NRC bodies. The CES has itself addressed this issue frequently (SSB, 1982, 1985). The U.S. Committee for the IGBP (the Committee on Global Change, or CGC) has written extensively on the complexities of the problem of modeling (CGC, 1986, 1988, 1990). The Bretherton report contains comprehensive diagrammatic representations of the earth system model (NASA, 1988). The NRC's Board on Atmospheric Sciences and Climate (BASC) has addressed modeling in a number of its reports, but perhaps the most significant is its 1991 data assimilation report (BASC, 1991), which addressed the integration of asynchronous, irregularly distributed measurements of varying quality and character. NASA also convened a special climate modeling workshop whose final report provided a broad survey of the challenges and requirements alluded to above (Unninayar and Bergman, 1993). All of these reports have stressed the intellectual challenge of the tasks before the MTPE and USGCRP.

Perhaps fittingly, in light of the difficulty of the research it supports, the EOS Data and Information System (EOSDIS) is the most complex civil data and information system yet conceived (Dutton, 1989). The task before NASA is not one of preparing a system specification, hiring the software and hardware systems specialists, and then awaiting the completion of a "turnkey" system, although there are elements of each of these. Instead, the task involves major, continuing research efforts as well. While some overall structures can be beneficially proposed and followed, the CES believes that development must proceed incrementally and must allow for frequent adjustments in direction as lessons are learned.

Data systems have been a perennial problem for the space and earth sciences for the entire history of the space program (see, e.g., Zygielbaum, 1993). The CES's choice to limit this historical review to the period beginning in the early 1980s neglects much of that history. The lessons learned have often been painful ones, with the early Landsat experience being particularly noteworthy. As a result, the NRC has written numerous reports and critiques of information systems (see, e.g., SSB, 1982, 1985, 1986, 1988a,b; CODMAC, 1982, 1986, 1988; NRC, 1990; and many others). Most recently, the NRC was asked to form a panel specifically to review the plans for EOSDIS. It was chaired by Charles Zraket, and its report called for a major revision of EOSDIS (NRC, 1994). The CES concurs with the Zraket panel's recommendations. In brief, the recommendations call for a user-driven design that is logically distributed and based on an open and fully extensible architecture. Those recommendations have been accepted by NASA.

### ASSOCIATED ACTIVITIES

There are a number of topics that do not fit neatly into the above categories. They include magnetic and gravitational field measurements, the use of the Global Positioning System (GPS), the importance of coordinated in situ measurements, and the role of the research and analysis (R&A) line in the NASA budget.

Over the long term, an enhanced measurement of the Earth's magnetic and gravitational fields will be a vital ingredient in global change research and operational applications. The history of the measurement of these fields by satellite is populated by more failed proposals than successful missions. The current USGCRP largely neglects the solid earth and its associated fields.

The advances being made in the application of the GPS may offer a lower-cost way to achieve important earth science and applications objectives. These include applications in many areas of the earth sciences. The NRC has considered some of these applications in analyzing GPS enhancements (ASEB, 1995).

No space-based system is entirely self-sufficient; all rely on in situ measurements, and all rely on advanced R&A for the interpretation of the results of space-derived data. Support for in situ measurements and experimental campaigns is widely dispersed in the government. The CES believes that it is vital that in situ measurements and campaigns be closely coordinated with the deployment of space-based systems, and that each is less effective if technical or budget problems thwart their parallel deployment where necessary. For example, intended support from the NASA Scatterometer (NSCAT) to investigations of the El Niño was precluded when NSCAT's launch was delayed until after the period of deployment of the in situ sensors.

The NASA budget contains a category termed R&A. R&A has customarily supplied funds for enhancing fundamental understanding in a discipline and stimulating the questions from which new scientific investigations flow. R&A studies also enable conversion of raw instrument data into fields of geophysical variables and are an essential component in support of the research required to convert data analyses to trends, processes, and improvements in simulation models. They are likewise necessary for improving calibrations and evaluating the limits of both remote and in situ data. Without adequate R&A, the large and complex task of acquiring, processing,

and archiving geophysical data would go for naught. Finally, the next generation of earth scientists, the graduate students in universities, are often educated by performing research that has originated in R&A efforts.

### THE ORGANIZATION OF CIVIL EARTH OBSERVATIONS PROGRAMS

As noted above, the United States is funding a variety of experimental and operational earth observations programs. They include EOS, Earth Probes, NOAA's polar-orbiting and geostationary operational satellites, Landsat, and the DMSP. Of these, only the NOAA and DMSP polar orbiters are currently planned to be merged, although Vice President Gore's National Performance Review recommended the further merger with the NASA MTPE satellites as well (Gore, 1993). At present, systems engineering practices are not being applied to the total U.S. satellite constellation. Overlapping functions suggest that economies of scale may be found in mergers of several or all of these systems. In addition, the oversight of both the earth sciences and operational applications support provided by these systems is fragmented. A full spectrum of options exists for reducing this fragmentation, ranging from maintaining the status quo (no improvement) to forming a single entity to oversee all civil earth observations.

International collaborations are an important part of both NASA and NOAA programs. In the area of international telecommunications, similar interdependencies led to the formation first of Intelsat and then of Inmarsat. Were the United States to take the step of creating a designated entity for civil earth observations, it might prompt other nations to do the same and possibly lead to a sharing of responsibilities analogous to that in the telecommunications industry. While there seems little prospect of near-term movement in this direction, it nevertheless seems unlikely that nations will permanently accept the high costs of orbiting national systems, when the same data could be gained from shared systems at lower cost.

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